A STEP TOWARDS INTEGRATED SAFETY SIMULATION THROUGH PRE-CRASH TO IN-CRASH DATA TRANSFER

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ABSTRACT

Occupant simulation methods in the area of passive safety address usually the investigation and prediction of crash dummy behavior after the time of collision. The development and optimization of active and also pre-triggered passive safety systems [1] require new simulation methodology including improved occupant models [2][3] and data transfer possibility between pre-crash and crash phase of a crash event. Prediction of occupant behavior in the pre-crash phase is one important enabler for such a new occupant simulation methodology dealing with optimization of integrated safety systems.

In this work, a semi-automated method is developed for posture and velocity data transfer between pre-crash Active Human Body Model (AHBM) and in-crash Human Body Model (HBM) or dummies. In one use case the application of the developed method is shown.

INTRODUCTION

Two questions are becoming more and more important to be answered with the increasing market penetration and number of functions from PRE-SAFE® and driver assist systems. The first one is how to capture the occupant kinematics and predict it in a pre-crash phase and the second one is how to evaluate its influence on a crash result. A PRE-SAFE®[1] system in general serves for pre-conditioning of the vehicle occupant and partly also of the car in a critical driving situation. Driver assist systems can perform driving maneuvers to mitigate a critical driving condition, e.g. undertaking a braking or steering action to avoid a suddenly appearing obstacle. During such PRE-SAFE® or/and assist system actions the occupant position may change depending on the occurring low-g loading condition.

The classical occupant simulation method deals with the occupant behavior in crash phase. However, it is becoming considerably important to predict the occupant behavior prior to a crash event because most countermeasures performed on a vehicle or/and occupant are prior to this event. These countermeasures may influence the occupant initial position at the start of an unavoidable crash phase. Therefore, coupling the pre-crash phase with crash phase would capture the vehicle and occupant dynamics in the crash simulation. Such a procedure enables the evaluation of the influence of e.g. PRE-SAFE® parameters like triggering times and belt force levels and further optimizations of those parameters.

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[1] PRE-SAFE® activates e.g. the reversible belt pretensioner, inflatable multi-contour seat bolsters for side support, seat movement as pre-conditioning (for passenger)

METHOD

Method overview

The simulation process chain consists of three main steps (cf. Figure 1). In the first one a reduced pre-crash model is created to provide a robust and fast base to simulate the pre-crash phase. The second step contains the pre-crash data processing and data creation for the in-crash phase. In the last step a crash model with the inputs from the previous step is created containing the pre-crash dynamics and geometric requirements.

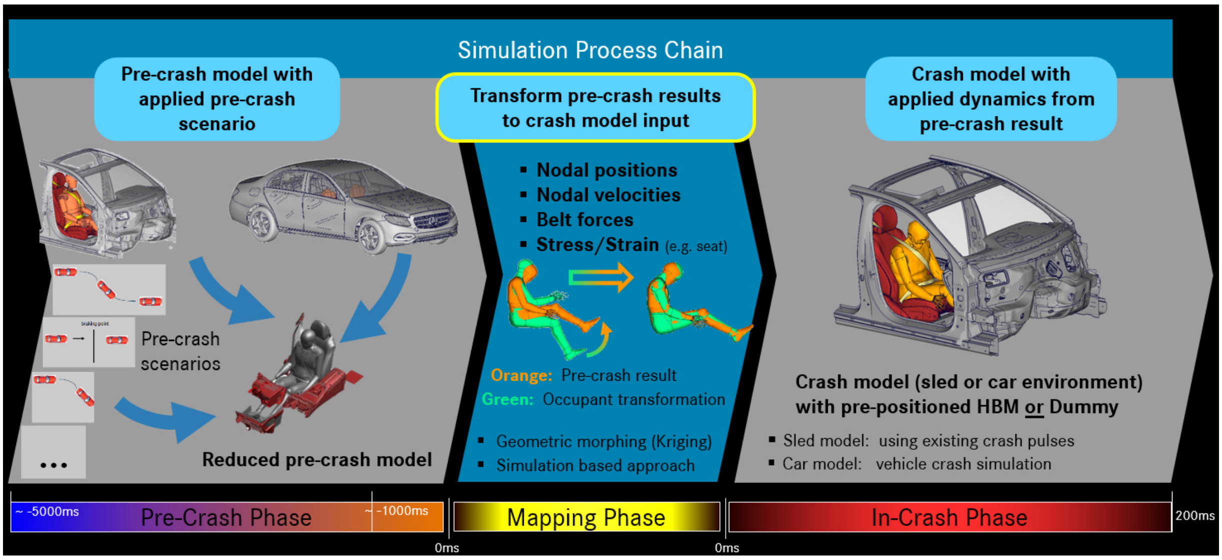


Figure 1: Overview of the Simulation Process Chain.

Due to the fact that simulation is not running in just one shot from pre-crash until the end of crash phase, it is possible to use different, optimized or suitable occupant models in each phase and also set up the crash configuration in a flexible way. That means by using the same pre-crash input it is possible to run different crash configurations.

Model setup of the pre-crash model

The pre-crash vehicle model is reduced as much as possible containing only the important surroundings of the occupant. Depending on the interaction possibility, parts having only slight contact with the occupant model are also switched to rigid material.

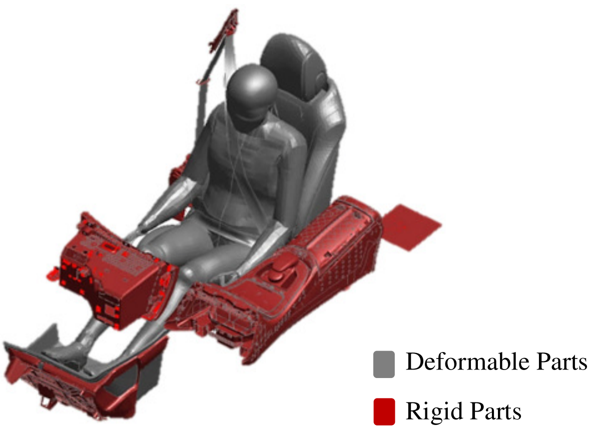


Figure 2: Pre-crash model set-up

The model contains mainly the seat, footwell area, parts of the instrument panel, center console & belt system. If needed the door trim could also be integrated. As occupant model the A-THUMS-D [4] model with active muscles is included.

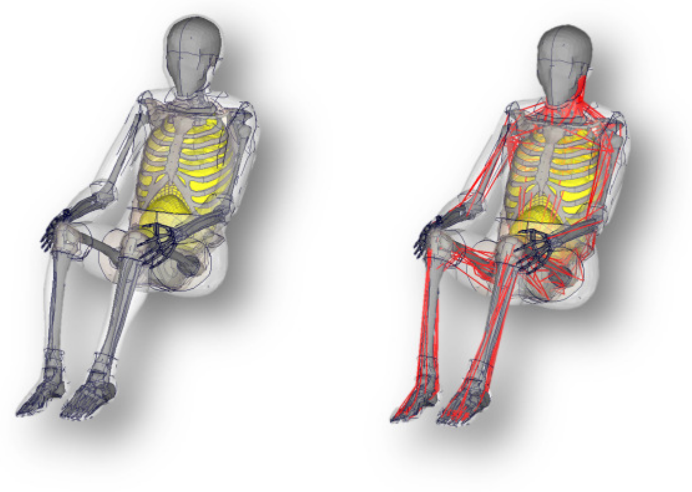
The boundary conditions representing the pre-crash maneuver could be derived from vehicle test data or from simulation data (e.g. accident reconstruction, vehicle dynamics simulation, etc.). This data could be imposed as acceleration, velocity or displacement boundary condition on the pre-crash model.

The main focus by setting up the pre-crash model is to reduce the CPU time and ensure the robustness since the required time frame is much longer (up to 5sec.) than the common used time duration for crash simulation. Due to long simulation time usage of the double precision version of the FE solver could be necessary.

Occupant Models for crash and pre-crash phase
For each phase a different version of the THUMS-D occupant model is used.

THUMS-D Human Body Model The HBM used in this study is the THUMS-D 50th percentile occupant model. The THUMS-D model represents a mid-size adult male occupant model, whose height and weight are 175 cm and 73.5 kg, respectively. The model is derived from THUMS® [5] classical version 1 & 3. This model was previously modified for in-house Daimler AG usage. The modifications conducted on this model involved mesh refinement in several body regions, connections in lower extremities and implementation of a new shoulder model. This model is henceforth, in the study is referred as THUMS-D as it was developed for the crash phase ("in-crash"). Figure 3 (a) below illustrates the THUMS-D model.

Active THUMS-D Human Body Model The *Active THUMS-D* human body model is developed based on "relaxed" THUMS-D which is derived from the THUMS-D explained above. Initial investigations made obvious that available HBM models and therefore also THUMD-D validated under high g loading conditions, are not applicable under low g conditions. There general behavior is too stiff and muscle control cannot be implemented directly. The details of relaxed THUMS-D model development are discussed in our research conducted previously [6]. Relaxed THUMS-D is then integrated with active muscles [4] to create *Active THUMS-D*. Figure 3(b) below illustrates the *Active THUMS-D* model ("A-THUMS-D").



(a) THUMS-D

(b) Active THUMS-D

Figure 3: In-crash & Active pre-crash Human Body Models

Data Transfer

As described in the previous sections, the pre-crash simulations are performed using a modified THUMS model that involves also active muscles to reflect the physical behavior of the human body during the low-g pre-crash phase and which also has been validated accordingly. On the other side, the in-crash phase requires a (mostly passive) model, which has been validated against in-crash (high-g) load cases. For the most general case, the pre-crash and in-crash models could be totally different in terms of meshing, materials and geometry, e.g. Active THUMS-D model for pre-crash and dummy model for the in-crash phase. Thus, no direct (one-to-one) relation between the two model meshes is available.

At the end of the pre-crash phase, the model's posture is obviously different from the initial standard posture (actual nodal positions) and also is in motion (actual nodal velocities), according to the pre-crash situation, e.g. lane change and/or braking maneuver. This requires a transfer of the nodal positions and velocities from the pre-crash to the in-crash phase. The latter is necessary to reflect the initial motion at the start of the in-crash phase. At the same time, a decent mesh quality has to be ensured to enable a stable simulation process of the in-crash phase and aspects of automation also have to be considered to include the data transfer method into a process chain with as little user interaction as possible.

AdaPT3 - Adjustment and Positioning Tool for Human Models To achieve this, a generic software tool is being developed by the authors to simplify and automate positioning and scaling processes with special applications to human body models (cf. Figure 4). Multiple geometric transformation procedures, like e.g. translations or rotations of model regions, are implemented, which are solely based on nodal relocations. The mesh smoothing of interfacial parts can be realized by simulations or interpolation methods like for instance the kriging or radial basis function methods.

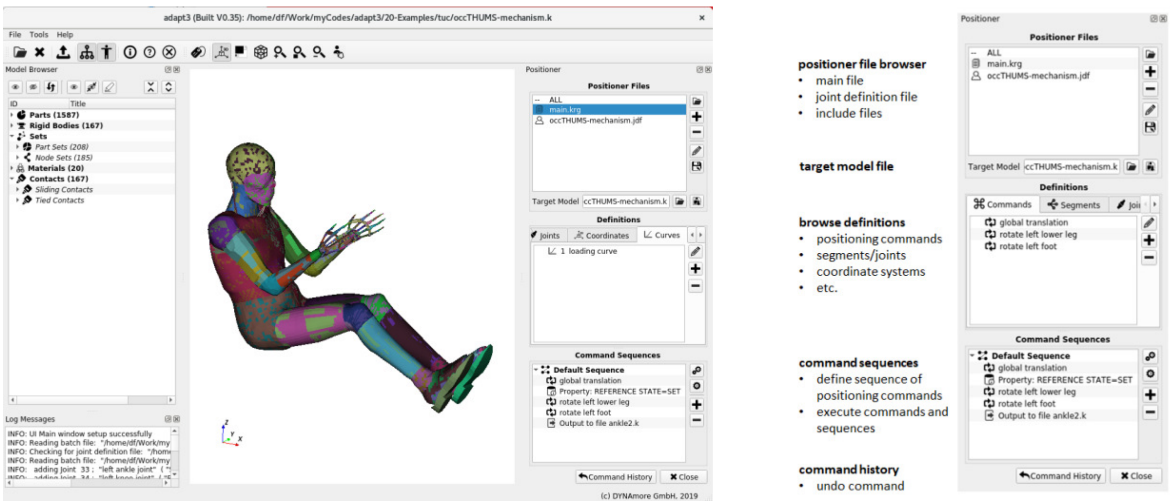


Figure 4: Main GUI of AdaPT3 showing the THUMS human model (left) and the positioner widget (right)

The tool is a generic tool which is not bound to a specific human model. The model dependency is rather realized by positioning and configuration files. Here model-specific definitions are given in terms of body segments (cf. Figure 5), joints, local coordinate systems or curves and task-specific definitions in terms of rotations, translations or scaling commands are specified to achieve a specific positioning task. These commands can be organized in positioning sequences and automatically run in a batch mode or interactively in the graphical user interface (GUI). Other features of the tool are for instance a browser for the positioning files, a command overview and history (UNDO) widget, a special-purpose positioner file editor, import/export capabilities and the possibility to interactively position the model or generate simulation decks.

Furthermore, functionalities have been implemented into *AdaPT3* to realize the posture transfer and the velocity mapping from the pre-crash to the in-crash models.

Data Transfer Approach In the following, the pre-crash model is also denoted as the source model, while the in-crash model will be referred to as the target model. Since in the most general case, no direct relations are present between the source and target occupant models, both models are divided into segments which will act as basic common properties. The segmentation might be realized as depicted in Figure 5 and includes the left foot, left lower leg, left patella, left upper leg, pelvis, etc.

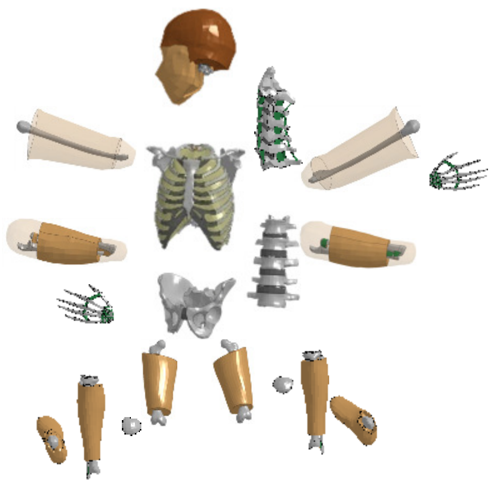


Figure 5: THUMS Model Segmentation

Based on this segmentation, the general mapping approach can roughly be defined using the following three steps

1. averaging of quantities within segments of the source model (pre-crash model)
2. transfer of averaged values between the models
3. distribution of averaged values to mesh of the target model (in-crash model)

The special implementations for the posture transfer and the velocity mapping are described in the following.

Posture Transfer

For the posture transfer, nodal positions have to be transferred from the source to the target models. Since no direct link is available between both meshes, the body segments of the target model are aligned to the segments of the source model. Therefore, local coordinate systems are defined on the body segments in the source and in the target model. To ensure a good model integrity and decent joint connections, the location and orientation of these local coordinate systems have to match the main features and the direction of the body segments. To perform the posture transfer, the local system of the target model is aligned with the local system of the source model and the nodes of the corresponding segment are updated accordingly. This implies that possible deformations of the segments are ignored which is acceptable since the segment deformations in low-g acceleration cases are mostly small in the pre-crash phase.

Please note that this step only repositions the body segments and the deformation of the joints and interfacial parts (e.g. knee flesh and ligaments, pelvis flesh) is entirely ignored. To adapt these interfacial parts, a model smoothing step is also required. This step can be based on geometric transformations or on simulations.

Simulation based positioning The most straightforward and mostly used approach is based on simulations (cf. Figure 6). A simulation deck is generated by the *AdaPT3* tool to move the body segments of the target model into the position of the source model. This is usually realized using the *string-pulling* or *marionette* technique, where string and damper elements pull the body parts towards the target position. The main advantage is that the physics, i.e. the material stiffness distribution and also contact interactions is accounted for during the simulation. However since current human models are still simplified in terms of representing real human anatomy and flexiblity, and this might lead to unphysiological motions also to unacceptable mesh quality. Another problem is that simulations can be very time consuming and postprocessing in terms of mesh smoothing and corrections might still be necessary.

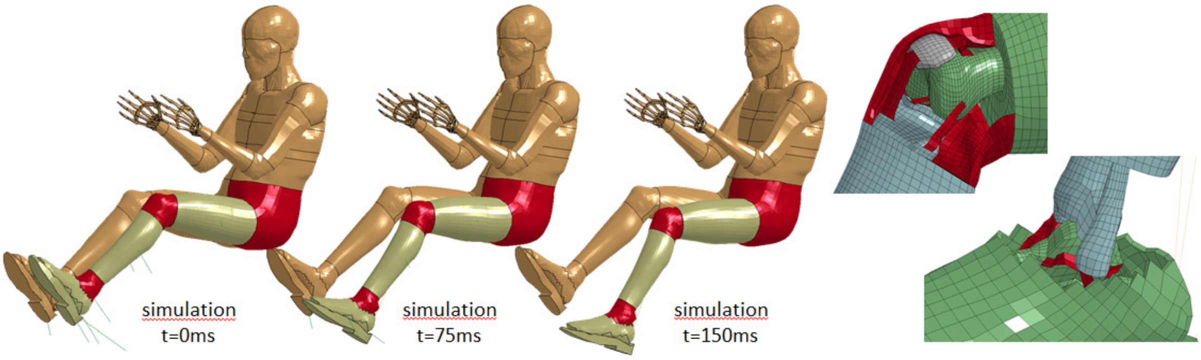


Figure 6: Posture adaptation using simulations

Positioning via geometric transformations Another approach is based on purely geometric mesh transformations using a kriging or radial basis function approach . Here the kriging method [7] is used to smooth the interfacial joint parts, e.g. the knee flesh or ligaments (cf. Figure 7). This requires the definition and decent choice of control points which define the basis for the interpolation approach. These control points are derived from the connected and prepositioned parts, like the upper and lower legs or the patella. The most important advantage of this method is the very fast execution time which is only a few seconds or minutes, depending on the number of control points. The mesh quality is also often better compared to the simulation results. However this method does not account for the physics of the model and might lead to problems in case of large posture changes. Thus the method should be restricted to small or moderate motions.

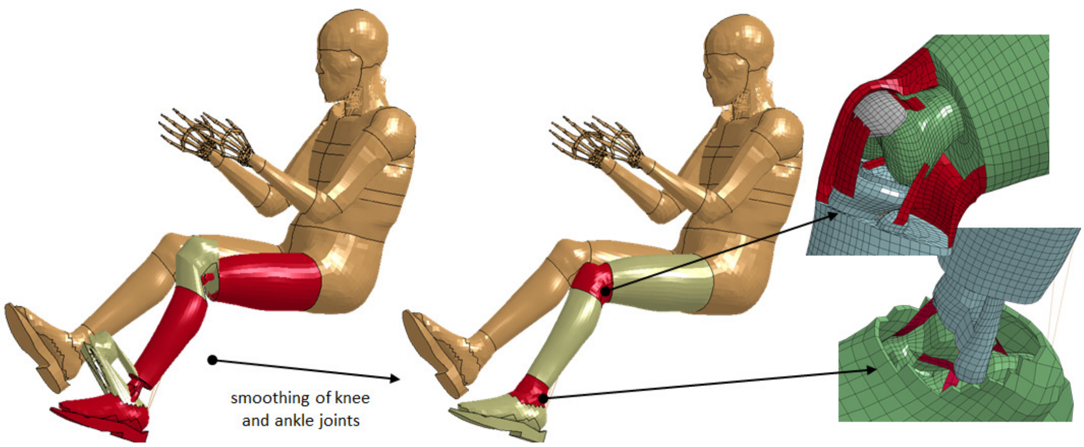


Figure 7: Smoothing of the prepositioned leg using the kriging method

Velocity Transfer

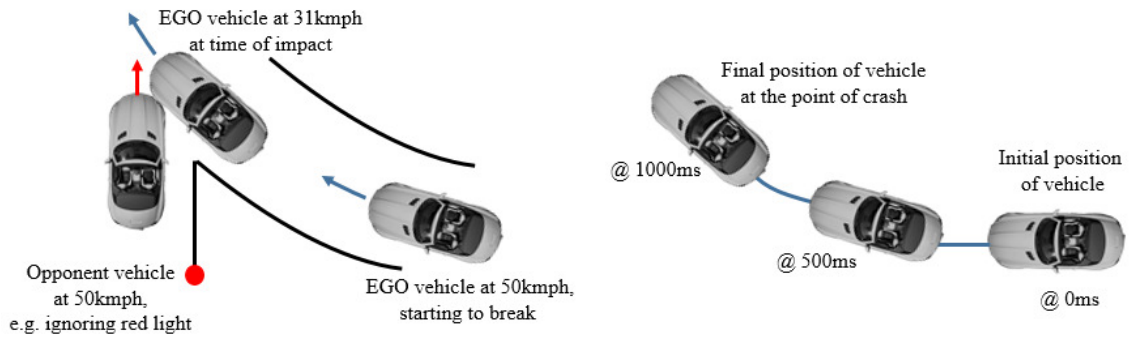
For the velocity transfer, again no direct link is available between the source and target models. Therefore the velocity mapping is again done on the body segment level where for each segment a representative set of nodes is selected. The nodal positions and velocities at the end of the pre-crash simulation are evaluated from the simulation result files. To compute the segment translational and rotational velocity, the nodal translational velocities are averaged over the source segment, the rotation center and the rotational velocities w.r.t. to the rotation center have to be computed on the source segment first. These quantities are then transferred to the target model and distributed to the nodes of the target segments using appropriate FE solver keyword cards. Finally, the simulation can be started using the initial segment velocities

Model setup of the crash model
The crash model setup comprises of standard decks either a sled model or a full vehicle model. The selection of the type of simulation deck depends on type of the load case. The methodology discussed above ensures the transfer of both the vehicle/sled model. Moreover, the flexibility offered by the tool chain is that it enables transfer of occupant data from pre-crash phase from Active HBM-to-HBM or Active HBM-to-Dummy.

APPLICATION IN COMBINED MANEUVER SCENARIO

The semi-automated methodology discussed above has been used for evaluating integrated safety – pre-crash and in-crash as a continuous event.

Pre-Crash maneuver
The present use case represents a simple conflict scenario. The ego vehicle is assumed to be travelling at 50kmph into another road, as shown in Figure 8a, having green traffic lights. The opponent vehicle e.g. ignores its red traffic light and, therefore, hits the ego vehicle from the side driving with a speed of 50kmph. The driver in the ego vehicle starts emergency breaking after becoming aware of the opponent car and decelerates from 50kmh to 31kmph at the time of impact.



(a) (b)

Figure 8: (a) Conflict scenario combined maneuver setup and (b) Vehicle trajectory during combined maneuver

Figure 9 illustrates the combined maneuver vehicle dynamic profile which was used to simulate pre-crash maneuver is based on the work conducted in OM4IS2 project [9].

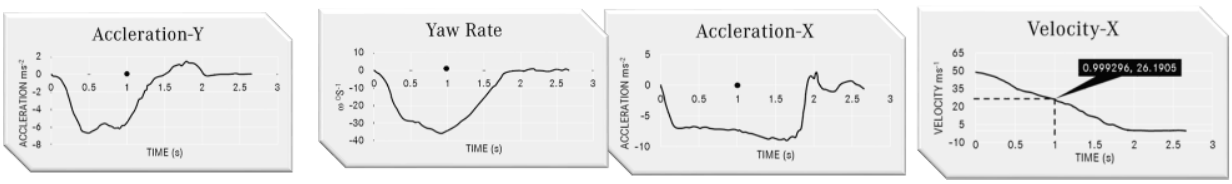


Figure 9: OM4IS2 combined maneuver dynamic profile [9]

The time duration of the pre-crash maneuver considered in this study is 1000ms. Figure 8b illustrates the vehicle trajectory and orientation at the end of pre-crash phase. The occupant under investigation is the passenger.

In-crash pulse generation

The crash pulse for conducting this study was generated from a vehicle to barrier impact (MDB-to-vehicle). The simulation was performed with position and velocity inputs from pre-crash end state. Figure 10 shows the full vehicle model and MDB configuration used for pulse generation. The vehicle FE model includes detailed BIW parts, engine compartment, doors, wheels and the suspension assembly etc.

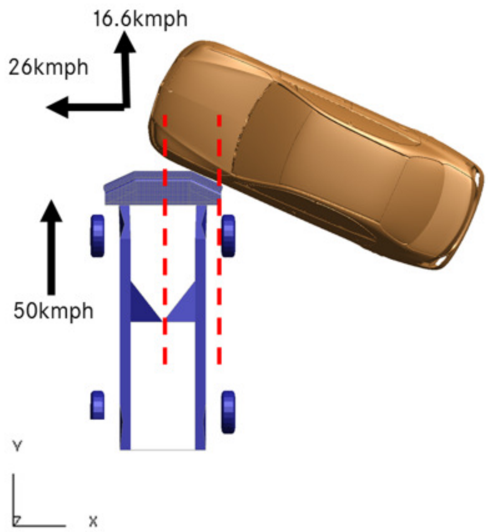


Figure 10: Final position of models for the full vehicle simulation

The motion pulse was generated based on vehicle kinematics using three nodes were minimal deformation was observed in structure. The displacement data from these three nodes were extracted and applied to the respective nodes in the sled to impart motion to the sled model. The sled simulation was overlaid over full vehicle simulation as illustrated in Figure 11 to verify transfer of displacement data which were now used in the FE sled model.

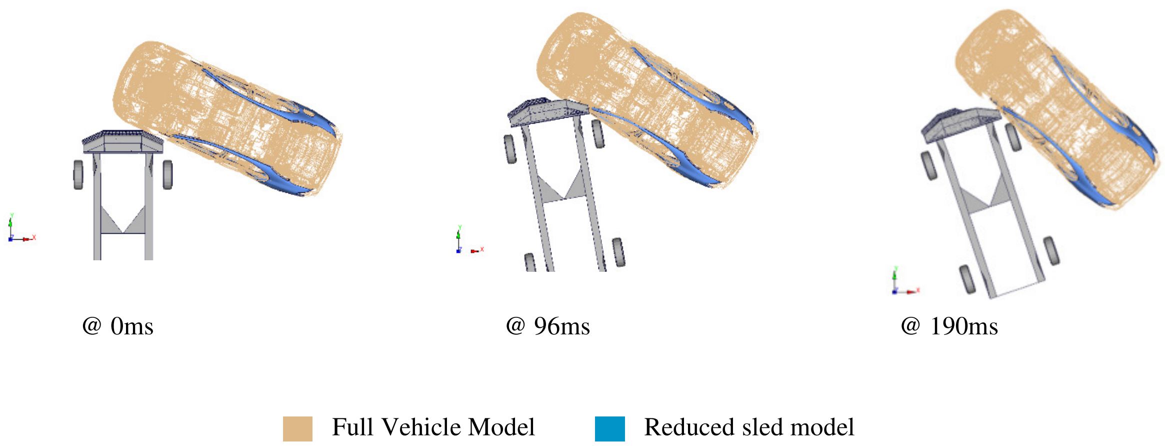
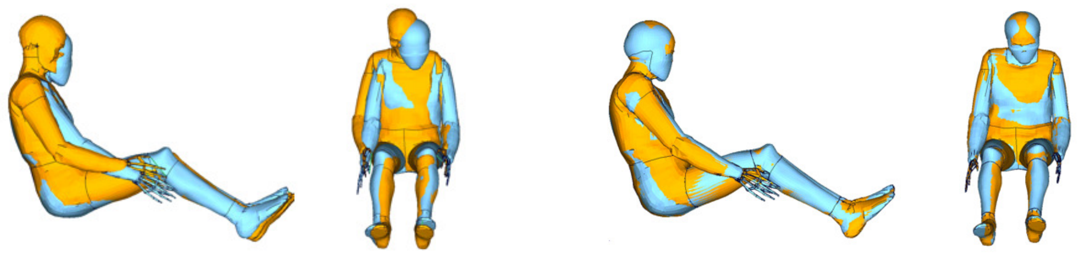


Figure 11: Sled model simulation overlaid over full vehicle simulation for extraction of motion pulse

Dynamic Occupant Data Transfer

The dynamic data at the end of the pre-crash phase was then transferred to in-crash phase model using the methodology above. The data transfer involved posture and velocity data transfer for the occupant. The in-crash HBM posture was generated using simulation approach (ref. Method section). Figure 12 shows the comparison of initial and final posture of the in-crash THUMS-D. The quality of the generated posture was evaluated by overlaying the initial state of in-crash and final state posture of pre-crash model as illustrated in Figure 12(b). The velocity data was transferred for individual body segments by estimating the average velocity of individual body region.



In-crash THUMS-D A-THUMS-D position from pre-crash last state

(a) (b)

Figure 12: (a) Initial position of the in-crash occupant (b) Final position of the in-crash occupant after pre-simulation

In-crash simulation carried out in sled model

The pre-crash vehicle response alters the occupant kinematics inside the vehicle. The occupant inside the vehicle starts reacting to the situation which is accomplised using A-THUMS-D for studying the effect of pre-safe system.

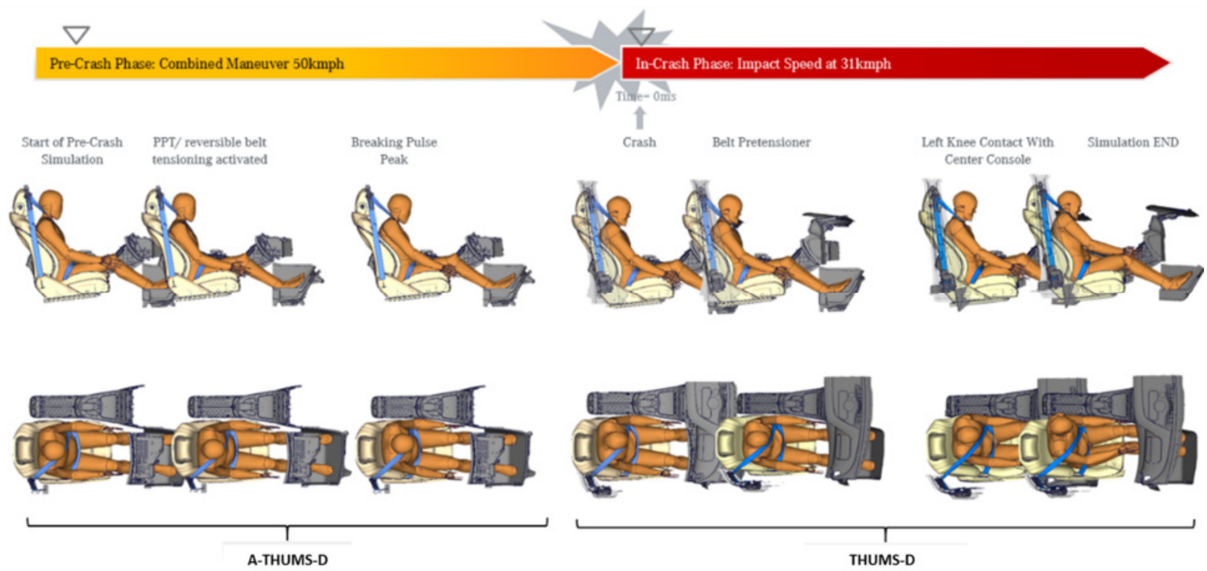


Figure 13: Occupant kinematics in pre-crash and in-crash scenario

In the current study, at 1000ms prior to impact brake assistant system is activated to avoid crash. The crash reversible pretensioner is activated to hold the occupant in seat at a given time point prior to crash. The influence of pre-crash vehicle dynamics moves the occupant closer to center console and instrument panel at the time of impact. The last state of pre-crash is the input for in-crash phase. In addition to the dynamic occupant data stresses in the seat were also transferred to the in-crash environment. The passenger airbag is not triggered and only the belt pre-tensioner is activated. Complete occupant kinematics from pre-crash to in-crash is illustrated in Figure 13.

DISCUSSION AND LIMITATIONS

The two methods developed for posture data transfer have their own strengths and limitations. The ‘geometric method’ is fast but is suitable only for small changes in posture while the simulation approach though relatively more time consuming can be used for cases with large posture difference commonly observed when doing pre-crash to in-crash data transfer. Local deformations on the pre-crash occupant are currently not considered in the posture creation for the crash occupant, since those are in generall small.

Velocity data is currently transferred through averaging for body regions where small velocity gradients cannot be captured.

CONCLUSIONS

Integrated safety evaluation for the vehicle occupants in the simulation environment raises the demand to cover and couple the pre- and in-crash phases with a suitable simulation methodology. The presented tool chain offers the use of optimized occupant and vehicle models for each phase and the transfer of the needed pre-crash dynamics as initial condition for the in-crash model. Since both phases running separately in the simulation, it is possible to run different crash configurations with the same pre-crash phase and vice versa. The required posture for the occupant in the crash model can be achieved by using the simulation approach or the faster geometric transformation with automatic smoothing steps.

The presented simulation method is a step towards the development of a seamless integrated safety tool chain.

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